Cocaine trafficking supply chain ODD

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1 Simulation ODD

WARNING: This ODD is still under construction, but will be completed before the final deadline of the corresponding paper

This section shows the conceptual design of an agent-based simulation which models the cocaine supply chain. The conceptual model is written in Overview, Design Concepts and Details format (ODD) (Grimm et al. [3]). The model extends on a legal supply chain implementation Jalbut and Sichman [4] by modeling it within the domain of illegal cocaine trafficking in Europe. With small changes in decision making and information sharing within the agents the illegal supply chain can be modeled. How the illegal market behaves can be analyzed by comparing legal and illegal.

1.1 Purpose

The purpose of this model is to see how supplier buyer dynamics work in an illegal supply chain.

1.2 Entities, state variables, and scales

The entities in the simulations are criminal syndicates, orders and shipments (Figure **??**). Each syndicate is implemented as one node/agent in the supply chains. The chain starts at the left with producers, these producers send shipments to internationals based on the orders of internationals. This process continues through wholesalers of either The Netherlands or Spain, then to retailer and finally ends at the consumers who consume the goods. The

model is based on work by Jalbut and Sichman [4], who have implemented a supply chain with trust.

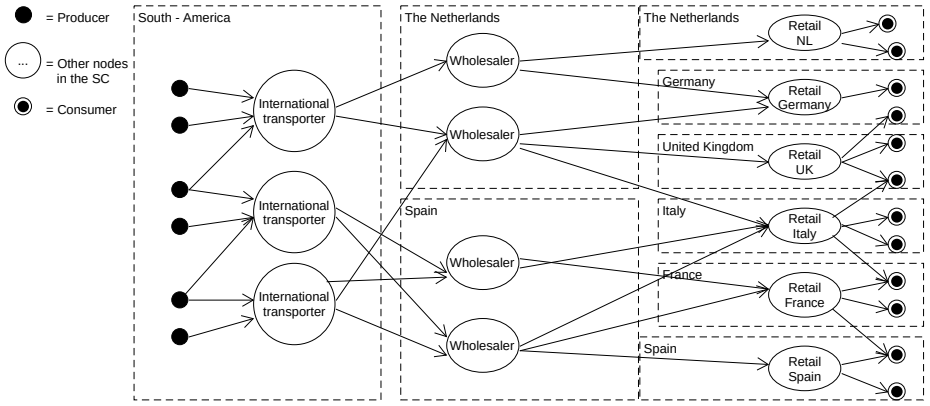

Figure 1: Simulation overview: showing the layout of the entities. Each arrow shows the direction of transport of the contraband.

Supply chain agents

The agents in supply chain are different variations of the same type of agent. Each of these agents contains the state variables given in Table 1. There are some variables that need some extra explanation: each agent has a country of operation, the ScType indicates the type of agent. The Relation contains the concepts of a relation between supplier and client, it is a HashMap with the ID of the supplier or client and a Relation Class (C). The stock is represented as a HashMap that contains a Byte (B) indicating the quality of the good and a Double (D) indicating the quantity of the good. The *security multiplier* influences the preferred stock with the expected demand. It acts as a multiplier, e.g. if the expected demand is 10 kg with quality 90 and the *security multiplier* is 2. Then the preferred stock is 20 kg with quality 90.

Table 2 shows the different agent types for each layer in the supply chain. The minimum and maximum sending sizes are roughly based on the schematic figure in Vermeulen et al. [5] (page 30). The different maximum package sizes are necessary for the supply chain to prevent a bottleneck at the wholesaler level. When there is an equal maximum shipment size (e.g. 10kg) a wholesaler with 2 suppliers (income of max 20kg per step) would

State variable	Type
ID	Integer
Country	Class
ScType	Enum
RelationsS	HashMap<ID,C>
RelationsC	HashMap<ID,C>
Name	name
Sell price	Double
Min package size	Integer
Max package size	Integer
Security multiplier	Double
Stock	HashMap<B,D>
Money	Double
New client cooldown	Integer
New supplier cooldown	Integer
Supply asked	Double

Parameter	Value
Shipment step	3
Produce amount	15
Consumer ticks remove	10
Living cost multiplier	5
Consumption min	0.5
Consumption max	5
Max number of suppliers	3
Max number of clients	3
Prob possible new min	

Table 1: Overview of parameters for nodes in the supply chain.

not be able to provide for 3 or more retailers (they require 30kg per step). The minimum package size is 5% of the maximum package size, to prevent extremely small amounts of goods to be send which could not be realistic. Dealers who usually sell around 50kg would not bother sending 2 grams to a client or this would be a rare exception.

Layer (ScType)	Min shipment	Max shipment
0. Producer → itself	5	100
1. Producer → international	5	100
2. International → wholesale	25	500
3. Wholesale → retail	5	100
4. Retail → consumer	1	20
5. Consumer	-	-

Table 2: Default state variable for each agent in different layers

Heterogeneous agents?

Initialize them with a random quality, half of the

Producers Producers produce goods an order to themselves, as in the beer game they do not need order processing and thus to time to produce is *shipment step* (Table 1). The producers have a fixed quality level that they produce, i.e. state variable: *Quality (Byte)*. The quality is dependent on cutting, according to Brosus et al. [2] this mainly happens at either the production stage or just after import in destination countries. They do not have a minimum to produce (only 0), just a maximum. There is a maxi mum or producers, this prevents and overflow of the market. An overflow in the market makes it to easy to supply consumers. There is a limit of producers set by ...TODO...

Consumers Consumers do not get directly removed when bankrupt. They are removed after a period of non using due to either stopping drug use or dying, *consumer ticks remove*. The spawning of consumers is dependent on the price of the drugs. The consumers are modeled as a group of consumers. Consumer income = $baseConsumption \times retailSellPrice$

Starting stock is zero

Wholesaler They can convert high quality to low quality, for each high quality they have they get 1.5 low quality. Because it can be seen as purity and with 2 kg of 60 purity, would leave 3 kg of 40 purity. To get more connection between the qualities.

Money

The selling prices are based on table 1 in Basu [1]. For simplicity the prices are abstracted starting with 1 and then using a rounded multiplication factor for additional steps in the supply chain. Table 3 shows the price of cocaine, the simulation price is derived by dividing the prices by the lowest price of $800. These lower numbers make it easier and more maintainable to experiment with the parameters in the simulation.

The starting money is defined by the multiplier $\times$ the buy price. Existing also brings costs with it, or else the networks could just be there without doing anything. Then I also need the stock to cost something. Then I have a very large amount of parameters.

Supply chain stage	Price per kg	Price in simulation per kg
Production & refining	$ 800	1
Import (Mexico)	$ 2,147	≈ 2.5
Export	$ 34,700	≈ 43
Wholesale & retail (U.S.)	$ 120,000	≈ 150 (country dependent)

Table 3: Cocaine price at different layers in the supply chain.

Goods, Orders & Shipments

The goods are the things that are produced, transported through the supply chain and finally consumed. They are represented by a HashMap¡Byte, Double¿ in which the Byte represents the quality and the Double represents the quantity. The client sends an order, this will arrive *shipment step* ticks later at the supplier. The supplier retrieves the order and decides how much to send to the client, the supplier creates a shipment containing the goods. The shipment arrives after *shipment step* ticks and is accepted by the client who will pay the supplier (Table 4).

State variable	Type	Parameter	Value
Client	Class	Order step	3
Supplier	Class	Shipment step	3
Goods	HashMap<Byte,Double>		
Steps left	Integer		
Price	*Double*		

Table 4: Parameters for orders and shipments, *italic* state variables are only for shipments

The moment a node is removed all of its outgoing and incoming orders and shipments are removed.

Countries

Countries are modeled to allow for matching data of cocaine prices and quality, differing levels of seizures and also to differentiate between transit countries (e.g. the Netherlands) and consumer countries (United Kingdom). The chain starts in Colombia, Bolivia and Peru which are the *producing countries*. From here *export countries* export the goods to the Netherlands and Spain which are transit countries for Europe (Vermeulen et al. [5]). From

here the goods are transported to other European countries for consumption. Table 5 shows the countries. The table shows a catch rate p, this is the probability of the police catching supply. The catch rates for the police are determined at the importing country. For example from export country to a wholesaler in the Netherlands (1→2) is mostly dependent on Dutch border control efforts. The retail price is based on data from the EMCDDA `http://www.emcdda.europa.eu/data/stats2018_en` There is a difference in quality (or purity) found across countries in Europe. This difference is based on data by the EMCDDA[1] by taking the mean of the mean per year. This is represented in the table for each European country.

Name	Layers	Price	Purity	$\rho: 0 \rightarrow 1$	$1 \rightarrow 2$	$2 \rightarrow 3$	$3 \rightarrow 4$
Producing	P	-	-	-	-	-	-
Export	I	-	-	0.1	-	-	-
NL	W, R, C	€50	57.92	-	0.2	0.1	0.02
Spain	W, R, C	-	47,43	-	0.2	0.1	0.02
UK	R, C	-	41.44	-	-	0.1	0.02
Germany	R, C	-	42.76	-	-	0.1	0.02
France	R, C	-	50.81	-	-	0.1	0.02
Italy	R, C	-	52,89	-	-	0.1	0.02

Table 5: Default countries, with corresponding layers, retail price per gram and catch probabilities ρ for the police on different layers of the supply chain.

For simplicity the quality in the simulation is either 40 or 60, the probability of a consumer graving a certain quality is based on the mean of that country. Lower mean quality means a higher chance of graving 40, and vise versa. This is represented by the following formula where $quality_i$ is the quality for agent $i \in I$, $quality_c$ is the mean quality for the given country $c \in C$, p is a random number with $0 \leq p \leq 1$.

$$quality_i = \begin{cases} 40 & \text{if } p \leq (\frac{max(quality_{c \in C}) - min(quality_{c \in C})}{quality_c - min(quality_{c \in C})}) \\ 60 & \text{else} \end{cases}$$

When wholesaler, retailers or consumers want to sell goods in other countries, they will pay extra, this cost will increase as the countries are

[1] `http://www.emcdda.europa.eu/data/stats2018/ppp` - Potency/Purity - Cocaine - Cocaine - Arithmetic Mean

further away from each other (Table 6).

Parameter	Value	Parameter	Value
Number of countries	Extra cost	Order step	3
1	€100	Shipment step	3
2	€300		
3	€500		

Table 6: Additional costs for country difference

Legal vs illegal

The supply chain modeled follows basic principles of

The illegal supply chain is made by making the chance of sending lower and by only allowing suppliers that are close by (distance of two). The closest one is always an option, the further away they go the less chance there is that they are an option.

Model scales

The spatial scale is international, agents reside in a specific country which can influence traveling time of the contraband. The temporal scale states that each tick is a week, the simulation can be run for a few years.

1.3 Process overview and scheduling

The basic process in the model is based on the supply chain in Jalbut and Sichman [4]. The process is given by pseudocode in Algorithm 1.

Border control & police *** Sometimes networks get removed by the police, this creates some vacancy in the supply chain. The vacancy is randomly filled up by a new agent who has a connection with one random supplier and one random client. Suppliers and clients of the agent can be asked for other suppliers and clients so the agent can expand his network. *** Not implemented yet

Removal When the amount of money is below zero it will be bankrupt and therefore destroyed. Sell to the most trust worthy persons. Thus new

Algorithm 1: Simulation flow

```
foreach round do
    Border control & police
    Mandatory payments & removal of bankrupt nodes
    Reset output parameters
    Spawning of new agents
    Move shipments one step further
    Move orders one step further
    Process arrived shipments
    Change of suppliers and clients
    Suppliers: take note of orders (for trust) AND send shipment
      to client Consumer: consumes
    Clients: send order to supplier, Producer: create a shipment
      for himself
end
```

people to the network are not being sold too. Removal of the supplier is done without removing the shipments that are already send, when a client receives such a shipment it is just accepted without paying for it. The shipments that go to the client are removed. The payment of stock is calculated by multiplying the quantity with the stock cost mult and the selling price. Since the selling price influences the scale of money for the nodes.

Spawning There is a spawn rate π for agents on each step.

Change of suppliers and clients This changing happens when the trust level is below a certain amount for all the .

When an agent has more than the security stock for every quality it will search for an additional client. This is important or else suppliers will be stuck with sometimes just one client. One client will not be enough for wholesalers and retailers as they need to deliver to multiple clients to make enough revenue.

You always know the closest supplier and client, the other known suppliers and clients are added dependent on a random function which adds suppliers or clients closer to the agent with a higher probability. Where i is this agent and j is the other agent.

$max(possiblenewmin, (1.0 - min(1.0, \frac{abs(y_j - y_i)}{Gridheight * possiblenewmult}$

List is ordered on highest average trust in supplier calculated by taking all trust relations from all it's clients. And vise versa.

Require new client and require new supplier is used. The producers has an adapted 'require new client' function that only looks at the security stock of the quality it can produce itself.

Any of the stock is smaller than the minimumPackageSize, then search for a new supplier.

Sending shipment Receive orders, if a client asks for a new quality, this quality will be added to the stock if the supplier wants to deliver it. When it is in the stock it will be ordered when sending orders.

The responsibility of sending is on the supplier side. The supplier makes the cost for sending, when the client receives it the client pays, otherwise the client does not pay. This is currently implemented on each layer. The payment is done instantly, the client just pays the supplier the full amount, even if his balance is below zero.

Send order The sending of orders happens for the clients, the following formula represents how the required amount is calculated. ***(Put this in formula: required goods : expected goods + (security multiplier * minimum package) - stock)*** The expected goods are the last ordered goods from each of the clients. The problem with this is the more they buy, the higher the stock should be. Which may be not necessarily realistic.

$$content... \tag{1}$$

Then for each quality they order at the most trust worthy supplier. They will take into account the minimum and maximum order size. On the chosen size the learning function is applied, even if the return value of the learning function is lower than the minimum package size, the client will ask the minimum package size.

1.4 Design concepts

Basic principles

The purpose of this model is to see the effect of police interventions on a supply chain, thus comparing legal and illegal supply chains. It give an

illustration of the usage of agent-based models in an illegal cocaine supply chain. This model can be shown to experts in the field to determine on which parts the model should contain more detail and to 'unlock' the restricted data.

Emergence

The criminal syndicates will try to get their contraband to the customer. The contraband and even in some cases the syndicate as a whole can be intercepted by police (with a certain probability). This could lead to disruption of the supply chain and decreased trust among criminals.

Adaptation

The agents can change their suppliers when the suppliers do not deliver enough. This is based on the trust factor which is calculated from the history of interactions between the supplier and client.

Objectives

The objective for the agents is to get the highest amount of payment through being able to supply the clients adequately while keeping stock low.

Learning

Trust is adapted over time by dealing with suppliers, this way the agents will learn which suppliers are reliable. The orders are influenced by a learning function that smooths the order quantity.

Prediction

The agents estimate the shipments needed based on the recent demand from their clients.

Sensing

The agents sense the incoming shipments and dependent on the *aware of supply intervened* know whether the missing shipment is due to the police

or due to the supplier.

Interaction

The interactions between agents in neighboring layers are sending or receiving shipments. The abstract police can intervene shipments and remove agents.

Stochasticity

The consumption of cocaine, the intercepted contraband and the catching of networks by the police is stochastically influenced.

Collectives

A chain within the economical network could be seen as a collective.

Observation

The amount of cocaine that is transferred and the amount that is caught will be collected. The stock, money and type of the agents will also be collected.

It is more interesting to see the cumulative cocaine that has been imported in the country. Since a good supply chain does not keep much cocaine on stock, but rather processes the cocaine as quick as possible. Cumulative stock is only to be added when it gets into a different country, now it is added when it enters the Netherlands, then when it enters the retail and again when it enters the consumers which triples the amount of cocaine in the Netherlands.

The produced and imported cocaine is only check from runtime, not with initial parameters.

Looking at the current import of wholesalers we can see through which path the cocaine flows.

1.5 Initialization

The initial state of the world is based on the parameters in table **??**. The parameters used are those combinations in which the model has a stable

supply chain (for 90% of the times, for 52 ticks), without change of policy. Then during the run the policy is introduced which measures the disruptive effect on the supply chain.

In the initialization phase the agents start with no stock (to get the supply chain going), a large amount of money, spawning is not allowed yet

Starting money and starting stock (the starting stock is the maximum security stock.

1.6 Input data

The model does not use input data to represent time-varying processes.

1.7 Submodels

The trust in a supplier is modeled by comparing the asked supply with the given supply. Since supplies can be intercepted by the police this is taken into account. The height of the parameter *aware of supply intervened* determines the awareness of criminal syndicates on loosing a package due to police intervention.

Order estimation

Who to order from is dependent on the supply succes rate and if the quality has already been received. The suppliers are sorted based on their trust (delivery succes rate). Suppliers get a trust of 0 when they have never delivered the chosen quality. For sending orders the following function is applied. Where φ_t is the placed order for time tick t, ψ_t is the required order amount, $0 \leq \lambda \leq 1$ is the learning rate and min_ps and max_ps are the *min package size* and *max package size* of the supplier.

$$\varphi_t = min(max\_ps, max(min\_ps, \lambda \cdot \psi_t + (1 - \lambda) \cdot \varphi_{t-1})) \tag{2}$$

Client only request orders that are within the ranges of the package size of the suppliers. Another check is done for the supplier to conform to the package size.

Trust

Trust is defined by the historical ration between the order places and the shipment received (Eq. 3). The current tick is described by n, i is the client, j the supplier, S_{ji} is the shipment received. *** maybe 7

$$Trust_{ij}(n) = \sum_{r=6}^{n} S_{ji}(r) / \sum_{r=1}^{n-6} O_{ij}(r) \tag{3}$$

The trust aspect described in Jalbut and Sichman [4] is the interpretation of trust from the client to the supplier. This supplier's trust is evaluated on the shipments that are correctly supplied. The trust in supplier will be mainly shown in the simulation. ***Important***, the trust is measured based on received shipments, in Jalbut and Sichman [4] a shipment that is send will always arrive. This differs in the illegal supply chain so now the order and the received shipment are compared.

The first trust is defined for client to supplier.

The second trust is defined for supplier to client. This is the time between the first order and now, thus the time they know each other. This trust will be $0 \leq Trust_{ij}(n) \leq 1$.

Connecting with people. If you have stopped cooperation with someone you can never cooperate with that person again.

Bigger shipments are compensations for previous missed orders, everything that is more than the ordered quantity will be penalized by the amount of *late shipment penalize mult*.

1.8 Simulation improvements

- search for suppliers when stock is under the minimum package size

1.9 Future work

- There are two types of agents, as in Jalbut and Sichman [4], i.e. *greedy* and *stable*. The stable against try to always being able to supply other agents by keeping an amount of contraband stashed. The greedy against do not hold extra stash.
- Adulteration could be added further in the chain as well. That agent

have the freedom of cutting their drugs. Either cocaine is cut at production or at wholesale level (just after importing). This is based on adulterants and solvents in cocaine and heroin in the paper by Brosus et al. [2].

- Different levels of concealment of shipments.
- Consumers may ask for a high quality, but are easily satisfied with a lower quality.
- legal market added to the illegal market
- Push of supply
- The dynamic between supply and demand. Make suppliers also able to push.

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